

A Comprehensive Harmonic Rejection for DFIG Feeding Non-Linear Loads in Stand-Alone Applications

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Abstract

This paper proposes a new control strategy to eliminate the harmonic components of stator current for stand-alone DFIG system feeding non-linear loads. In this method, the LSC operates as an active filter which is controlled by employing a proportional-integral and a resonant controller. And also, the stator current is used as the feedback signal for the compensator instead of the load current, so that the additional current sensor at the load side can be removed. The experiment is verified to validate the effectiveness of the proposed compensating method.

1. Introduction

In recent years, the Doubly-Fed Induction Generator (DFIG) has become the most important generator for wind energy system. Even though most of literatures are focused on grid-connected application, the operation in stand-alone mode should be concentrated on to fulfill the theory of the DFIG machine.

In stand-alone operation, the electrical quality of system is sensitive with the characteristic of loads, especially the non-linear load. The system configuration of the stand-alone DFIG system feeding non-linear load is shown in Fig. 1. In Fig. 1, the stator voltage and current are polluted by the positive $(6n+1)$ and negative $(6n-1)$ order harmonics, so that the other loads connected to DFIG are impacted seriously. Therefore, many researches are discussed about how to eliminate these harmonics. The LC filter which plays a role of low-pass filter is designed in [1] for aircraft application, but the resonance phenomenon can be appeared and the system becomes unstable. In [2], the rotor harmonic current is generated by controlling the rotor-side-converter (RSC) to eliminate the harmonics of stator voltage, but the torque pulsation and rotor heating cannot be reduced. To deal with this problem by using the load-side-converter (LSC), the harmonics of LSC current are produced to compensate the corresponding components of stator current with the sensorless control theory [3]. However, because only the PI controller is applied in the compensator, so the steady-state errors of magnitude and phase are not guaranteed.

This paper proposes a new control algorithm to reject the harmonics of stator current by the LSC controller in case non-linear loads are connected to stator side of DFIG. In this method, the stator current is applied as a feedback signal to the current controller instead of the load current. Thus, the cost of system is reduced as compared to previous methods because the additional current sensors at load side can be removed. In the current regulator, one proportional integral and one resonant controller at six multiples of synchronous frequency are applied in the fundamental reference frame to eliminate the fifth and seventh harmonic of stator current. The proposed control method is explained in detail and confirmed by the experiments.

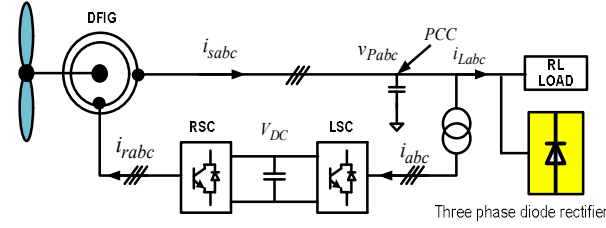


Fig. 1. Configuration of stand-alone DFIG system feeding non-linear load.

2. Proposed LSC Control Method

In normal condition, the main function of LSC control is to produce the dc-link voltage and to adjust the input power factor of the front-end converter. The fundamental component of d -axis of the LSC current is responsible for the former while its q -axis of is applied for the latter. These components are adjusted by the PI controller, which are given by

$$\begin{cases} i_{d0}^* = \left(K_p + \frac{K_I}{s} \right) (V_{DC}^* - V_{DC}) \\ i_{q0}^* = 0 \end{cases} \quad (1)$$

Under non-linear load condition, the LSC control is also responsible to produce the sinusoidal stator current. For this purpose, the LSC is controlled as an active power filter to generate the harmonics of the line current to eliminate the harmonics of stator current. The stator current is sum of load current and LSC current. These currents can be expressed in fundamental reference frame as

$$i_{sdq} = i_{Ldq} + \frac{i_{dq}}{k} \quad (2)$$

Decomposing into fundamental and harmonic component, (2) can be rewritten as:

$$i_{sdq0} = i_{Ldq0} + \frac{i_{dq0}}{k} \quad (3)$$

$$i_{sdqh} = i_{Ldqh} + \frac{i_{dqh}}{k} \quad (4)$$

From (4), the overall method to achieve the zero harmonic stator current is to generate the LSC current which has same magnitude but opposite phase to the load current for each harmonic component:

$$\begin{cases} i_{dh}^* = -k \sum i_{Ldh} \\ i_{qh}^* = -k \sum i_{Lqh} \end{cases} \quad (5)$$

In order to remove the load current sensors, the reference value for harmonic of LSC current is inferred from (4) and (5):

$$\begin{cases} i_{dh}^* = -k \sum i_{Ldh} = i_{dh} - k i_{sdh} \\ i_{qh}^* = -k \sum i_{Lqh} = i_{qh} - k i_{sqh} \end{cases} \quad (6)$$

Next, the errors between total component value of line current and its measured value are expressed from (4) and (6):

$$i_{d_err} = i_d^* - i_d = i_{d0}^* - ki_{sd} + (ki_{sd0} - i_{d0}) \quad (7)$$

$$i_{q_err} = i_q^* - i_q = -ki_{sq} + (ki_{sq0} - i_{q0}) \quad (8)$$

In (7) and (8), i_{d0}^* and i_{q0}^* are evaluated by (1), while the dc components $(ki_{sd0} - i_{d0})$ and $(ki_{sq0} - i_{q0})$ are achieved through a LPF from the corresponding term of stator and LSC current.

As can be seen from (8), in the fundamental rotating reference frame, the inputs of current controller consist of dc and harmonic components at the frequencies of $6n$ multiples synchronous frequency. In this paper, the sixth harmonic component ($n = 1$) is rejected by a resonant (R) controller while the dc component is regulated by the proportional integral (PI) controller. As a result, the PI-R controller is used for the compensator as illustrated in Fig. 2. Fig. 3 shows the detail of the proposed compensating method for the LSC controller.

3. Experimental Results

In order to validate the effectiveness of proposed method, the experiment has been carried out. The LSC and RSC are controlled by a control board of DSP TMS320F28335 of Texas Instruments with the switching frequency at 5 kHz. A three-phase diode rectifier which plays a role of non-linear load is connected to stator of DFIG.

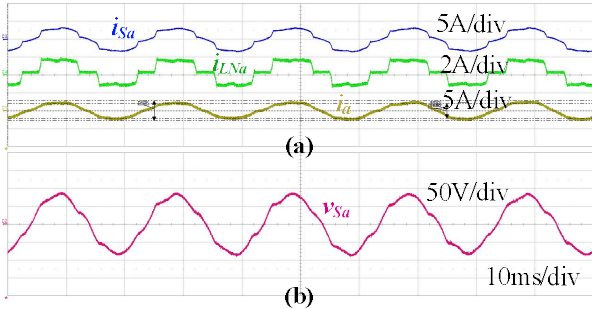


Fig. 4. System performance without compensation (a) From top to bottom: Stator current, load current, LSC current. (b) Stator voltage.

Figs. 4(a) and 5(a) show the current waveforms for stator, non-linear load and LSC from top to bottom without and with compensating method, respectively. As shown in Fig. 4(a), without compensation, the stator current is seriously distorted by receiving the harmonics of load current while the line current is almost sinusoidal. In contrast, the compensating harmonics of line current are generated to make the stator current sinusoidal in Fig. 5 (a).

Figs. 4(b) and 5(b) show the waveforms of stator voltage without and with the proposed method, respectively. From the experiment, we can say the quality of stator voltage is improved much better thanks to the stator current compensator.

4. Conclusion

This paper has presented a new control approach for stand-alone DFIG system under non-linear load condition. In this method, the stator current is directly used for the controller to remove the additional current sensors in load side. Therefore, the cost of system is reduced while the quality of stator current and voltage are improved. In addition, the control method is simplified by applying the LPF and PI-R controller to the current regulator. The experimental results evaluate the effectiveness of the proposed compensating method.

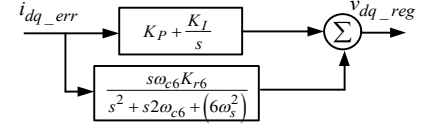


Fig.2. PI-R Controller.

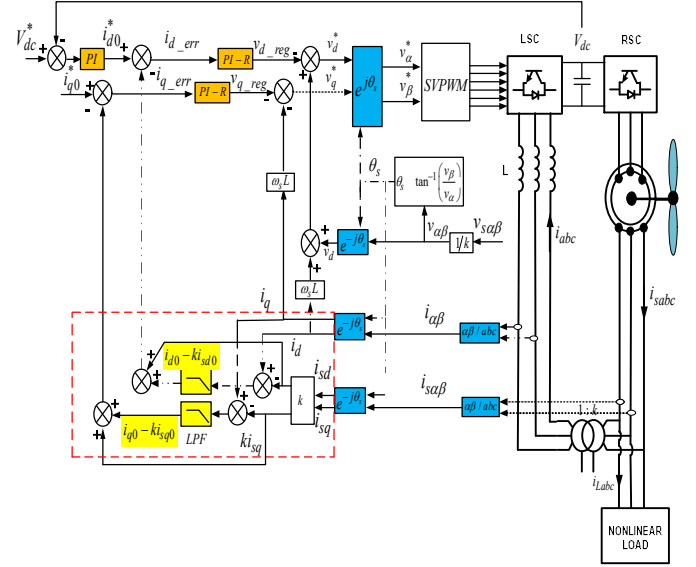


Fig. 3. Proposed LSC control method.

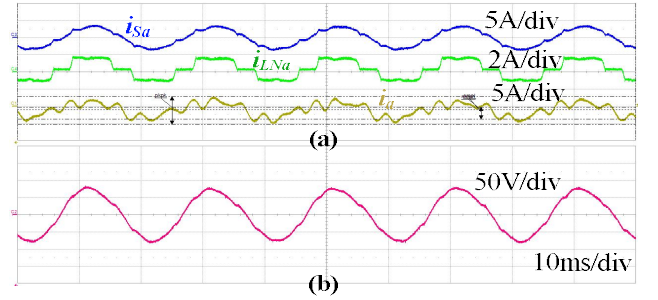


Fig. 5. System performance with compensating method (a) From top to bottom: Stator current, load current, LSC current. (b) Stator voltage.

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Reference

- [1] Khatounian, F.; Monmasson, E.; Berthereau, F.; Louis, J.P.; , "Design of an output LC filter for a doubly fed induction generator supplying non-linear loads for aircraft applications," *Industrial Electronics, 2004 IEEE Int Sym on* , vol.2, no., pp. 1093- 1098 vol. 2, 4-7 May 2004.
- [2] Van-Tung Phan; Hong-Hee Lee;"Control Strategy for Harmonic Elimination in Stand-Alone DFIG Applications With Nonlinear Loads," *Power Electronics, IEEE Trans. on* , vol.26, no.9, pp.2662.
- [3] Jain, A.K.; Ranganathan, V.T.; "Wound Rotor Induction Generator With Sensorless Control and Integrated Active Filter for Feeding Nonlinear Loads in a Stand-Alone Grid," *Industrial Electronics, IEEE Trans. on* , vol.55, no.1, pp.218-228, Jan. 2008.